

Oil sands exploration in Ijebu-Imushin using magnetic and electrical resistivity methods

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ABSTRACT

There has been tremendous interest in the exploration and production activities of readily available alternatives to conventional oil. Oil seeps observed in Ijebu-Imushin, Ogun State, south-western Nigeria, served as an indication of the occurrence of oil sands – a non-conventional hydrocarbon resource – in the area. Electrical and ground magnetic geophysical survey techniques were thus employed to map the occurrence of the oil sand deposits in the study area as well as to determine the depth to the basement in order to obtain information on the subsurface for exploitation activities. Three vertical electrical soundings and 2-D electrical imaging along a single profile were carried out using the Schlumberger and Werner configurations, respectively. Modelling the likely subsurface structures from the measured magnetic profiles indicates a likely maximum depth to basement of 300m across the study area. The constructed strata from the electrical methods revealed that oil sands deposit are likely to be present and substantial in the south-western part of the study area. The deposit appears to commence from a depth of about 2 m, extending to a depth of approximately 40 m in this part of the study area.

Keywords: Oil sands, conventional oil, electrical resistivity, ground magnetic survey, Ijebu-Imushin.

INTRODUCTION

Oil sand is composed mainly of sand, heavy oil and clays that are rich in minerals and water. The heavy oil present in tar sand is what is otherwise referred to as bitumen. In the crude state, bitumen is a non-crystalline, sticky, viscous substance. It is either black or dark-brown in appearance and essentially consists of hydrocarbons. The continued depletion of petroleum resources, aggravated by increased demand, has created an urgent need for the development of alternative or additional sources of energy. Being an energy resource material, bitumen has found a complimentary role to other energy resources such as coal, crude oil and natural gas and promises to be an indispensable alternative energy resource. To this end, several scientific and commercial investigations have been focused on the bitumen belt of south-western Nigeria to delineate the deposits and understand their relation to sub-surface hydrocarbon accumulation in the region.

Bitumen was first discovered in Nigeria in 1900 in a belt stretching from east of Ijebu Ode (Ogun State) through Okitipupa (Ondo State), Benin (Edo State) and then in Lagos State (Figure 1). A series of drilling programmes between 1907 and 1914 by the defunct Nigerian Bitumen Corporation (NBC), following the trend of the outcrop belt from north-east of Lekki-Lagoon in Ogun State to the south-east in Ondo State

confirmed the occurrence of bitumen and showed the presence of associated elements and minerals such as sulphur and pyrite (Ministry of Solid Mineral Development, 2006). Coursey *et al.* (1963), under the auspice of the Federal Institute of Industrial Research and Tennessee Nigeria Inc., carried out some analyses to ascertain the possibility of *in situ* recovery techniques of extracting heavy oil. Enu (1985, 1990) described the nature and occurrence of the Nigerian tar sand, remarking that it is made up of 84% sand, 17% heavy oil (or bitumen), 4% water and 2% mineral clay. He also studied the porosity of oil sands and observed that the porosity of tar sand ranges between 16% and 35%. The sands also contain some heavy minerals which include opaque, staurolite, tourmaline, zircon, rutile, garnet and andalusite, some of which could be economically exploited.

Nigeria's reserves of oil sands are estimated to be 30 to 40 billion barrels of heavy oil in place with future potential recovery of $3,654 \times 10^6$ billion barrels (Adegoke *et al.*, 1991).

Geophysical techniques have been used extensively for mineral resources exploration with the type of mineral sought after informing the geophysical prospecting technique to be employed. Other exploration techniques include geological mapping, topographic/terrain mapping and drilling/coring (Ako, 2003). As oil sands

occur at shallow depth of less than 1,000 m (Chopra and Lines, 2008; De-Hua *et al.*, 2008), geophysical techniques suited to shallow exploration were employed. Specifically the electrical resistivity method (1-D and 2-D) and the magnetic method of geophysical survey were employed for this study.

Geo-electric methods have been used successfully in oil sand detection, since it is an efficient method for delineating shallow layered sequences or vertical discontinuities involving changes in resistivity. The significant thickness relative to depth, as well as the very high resistivity contrast with the host geology (Baum, 2005), contributes to the success of geo-electric techniques in oil sands detection. Example is in the application of electromagnetic airborne techniques (Cristall *et al.*, 2004) in finding best deposits. A 1-D resistivity survey has also been employed in direct detection of the Alberta hydrocarbons (Bauman, 2005) and Nigerian oil sands (Ako *et al.*, 1983).

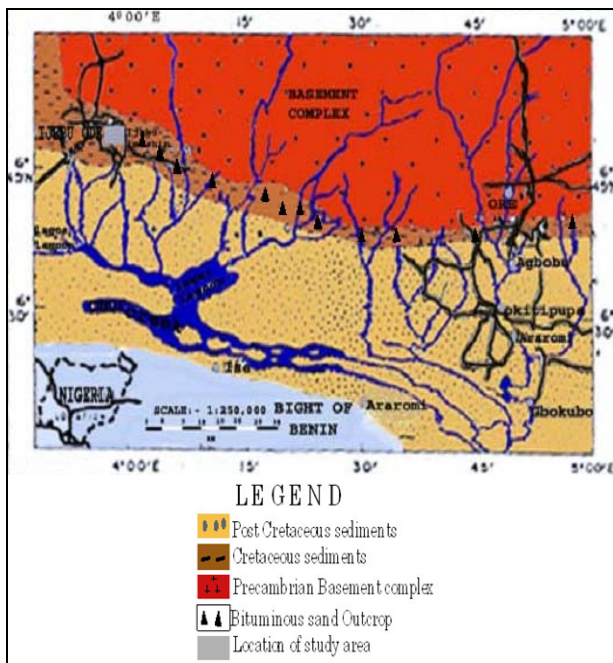


Figure 1. Geological map of south-western Nigeria showing the tar sands outcrop belt (modified from Enu, 1985)

Oil seeps observed in Ijebu-Imushin in Ijebu East Local Government of Ogun State, south-western Nigeria, served as an indication of the occurrence of bitumen in a subsurface reservoir in that area. Geophysical exploration techniques (magnetic and electrical resistivity) were therefore employed in this study to map the oil sands deposit in the study area as well as to determine the depth to the basement in order to obtain information on the subsurface conditions with a view on exploitation activities.

Physiographical and geological setting of the study area

The study area (Figure 2) is located at 06°46'53"N and 03°58'23"E. This location falls in the village of Imeri of Ijebu-Imushin, Ogun-State, south-west Nigeria. The village is just off the Lagos-Benin Express Road to the east. The area has a moderately high humidity, while the mean temperature ranges between 25°C and 28°C.

The oil sand belt falls within the Nigerian sector of the Dahomey basin (i.e. the eastern end of the basin). Various workers have rendered their service at piecing together the stratigraphy of the eastern Dahomey basin, these includes Russ (1924), Reyment (1965) and Agagu (1985). The stratigraphy of the basin was also reviewed by Omotsola and Adegoke (1981) on the basis of new data that had become available. In most parts of the basin the stratigraphy is dominated by a monotony of sand and shale alternation with varying minor proportions of limestones and clays. The lithostratigraphy is as follows (from the oldest material overlying the basement complex to the youngest): the Abeokuta Group, the Imo Group, the Ilaro Formation, the Benin Formation and the Recent Alluvium.

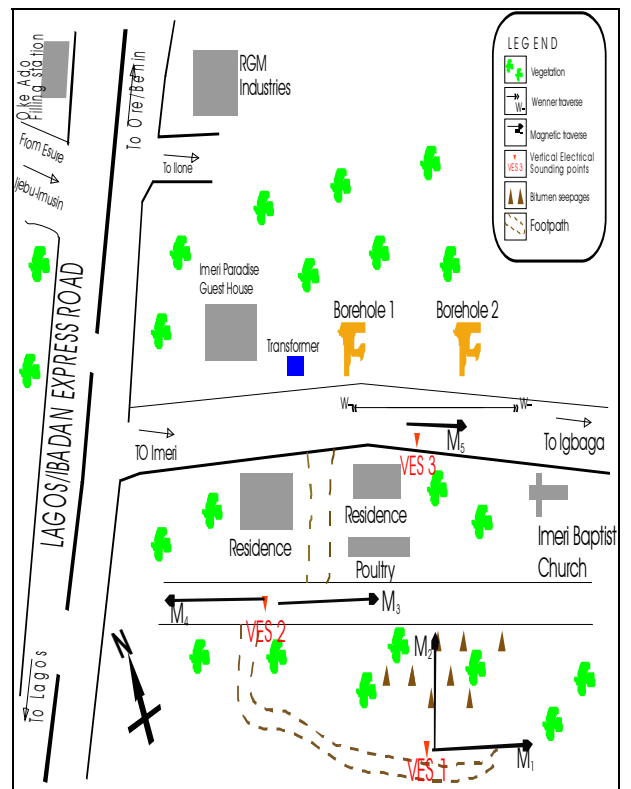


Figure 2. Base map of the study area

The study area, however, is located on the outcrop region of the Abeokuta group of the eastern Dahomey Basin (West Africa), and the age is given from Neocomian to Palaeocene (Ministry of Solid Minerals Development, 2006). This group has been sub-divided into three distinct formations by Omatsola and Adegoke (1981), namely the Ise, Afowo and Araromi Formations (from the oldest to the youngest). The sub-division is based on lithological homogeneity and similarity of

origin. The Afowo Formation sediments are composed of inter-bedded sands, shales and clays and ranges from medium- to fine-grained in texture (Omatsola and Adegoke, 1981; Agagu, 1985). The formation indicates the commencement of deposition in a transitional environment after the deposition of the basal and continental Ise Formation (Ministry of Solid Minerals Development, 2006). Outcrops of this formation are commonly encountered within the oil sand belt. They are easily recognizable because of the presence of sticky and viscous heavy oil seeping from the sandy portions of the formation. The age of this member of the group is put as Maastrichtian (Agagu, 1985).

METHOD AND RESULTS

Electrical Resistivity Survey

The electrical resistivity method is a geophysical technique that utilizes a low-frequency, alternating current, artificially introduced into the ground by means of a pair of electrodes. The electrical potential difference is then measured by means of a second pair of grounded electrodes. Measurements of the injected electrical current and potential difference, as well as the distances between the different electrodes, may be used to calculate an apparent resistivity for the earth at a specific position and (pseudo-)depth. The apparent resistivities recorded during a survey may be inverted to obtain a model of the resistivity distribution within the subsurface. The instrument used for the electrical survey was the IRIS instrument, model SYSCAL JUNIOR Terrameter (serial number 102).

Three Vertical Electrical Soundings (VES) were carried out using the Schlumberger configuration. The maximum half electrode spacing (AB/2) was limited to 40 m due to the topography of the area. The apparent resistivity values obtained was then plotted against the corresponding AB/2 spacing on bi-logarithmic paper. Partial curve matching of the data yielded geo-electric parameters which were then used as starting model parameters for the computer aided inversion. The interpretation of the data was done using the WinGlink [TM] software, version 1.62. The pseudo-section and modelled cross-section were also generated using this software.

A summary of the subsurface information obtained from the interpretation of the resistivity data is presented in Table 1, while the pseudo-section and cross-section obtained from the interpretation are presented in Figure 2 and

Figure 3 and (both in the east-west direction).

Table 1. Summary of the VES interpretation

VES No.	Layers	Resistivity (Ωm)	Thickness (m)	Depth (m)
01	1	622.42	1.63	1.63
	2	210.04	1.89	3.52
	3	796.77	1.20	4.72
	4	3,864.75	-	-
02	1	829.51	1.88	1.88
	2	1,350.87	0.60	2.48
	3	3,409.61	1.41	3.89
	4	15,456.12	-	-
03	1	40.38	0.88	0.88
	2	52.71	2.10	2.98
	3	23.29	5.40	8.38
	4	41.62	2.92	11.30
	5	504.09	-	-

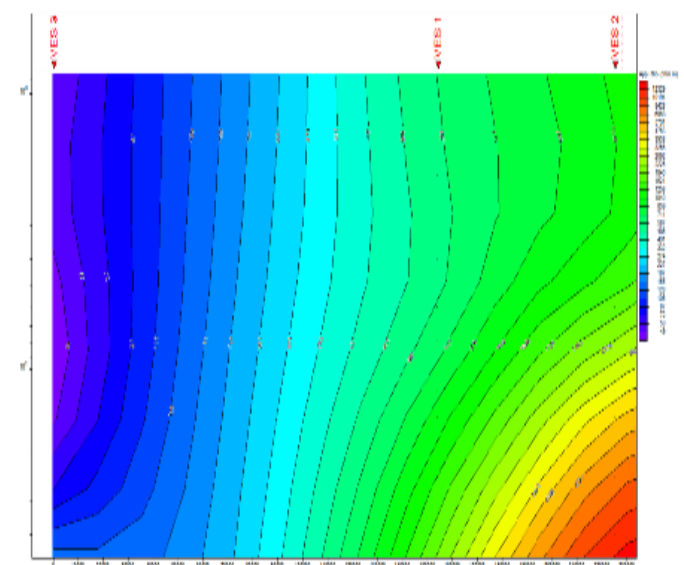


Figure 3. The pseudo-section along the VES points in the E-W direction.

The pseudo-section (

Figure 3) shows higher resistivity values at VES1 and VES2 while lower resistivity values are observed at VES3. The lower resistivity values at VES3 suggest that this site may be a good prospect for shallow underground water. Observing the modelled cross-section in Figure 4, it again appears that VES3 occurs in an area with shallow water-bearing sediments due to the relatively low values of the modelled resistivity. The longevity of an existing borehole in the area, as attested to by the indigenes of the area, seems to confirm this interpretation.

Along the modelled cross-section an increase in resistivity with depth, with very high values towards the western part of the section (VES2), is observed. The elevated resistivity values are probably due to the

occurrence of oil sand deposit in this area. Seepages observed can possibly be attributed to the flow of bitumen to the eastern parts of the study area (VES1) since VES2 is located at a higher elevation.

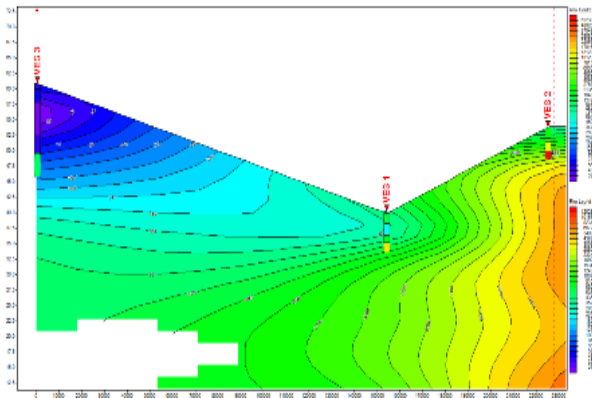


Figure 4. Modelled Cross-section along the VES points in the E-W direction.

The 2-D electrical imaging measurements also involve injecting current into the ground by means of two electrodes and calculating the apparent resistivity. The Wenner configuration was used to carry out lateral profiling of the sub-surface at different depths to ascertain the expanse of the subsurface features. This was done along one profile with lateral traverse span of 180 m in a west-east direction. Interpretation of the data obtained was achieved using the DIPRO[™], geophysical software to invert the recorded field data. This process involves the integration of lateral variation with the corresponding depth variation as seen in Figure 5. Inferences and conclusions on the regolith material were made based on the known geological conditions of the study area.

From 0 m to 40 m on the traverse, a region of light green to yellow colouration with resistivity range of 200.0 to 440.0 Ωm to a depth of 10 m is apparent. This area probably signifies sandy material with little bituminous presence. Between 44 m to 74 m along the traverse, blue to green colouration with resistivity range of 0.31 to 200.0 Ωm is observed. This low resistivity region possibly indicates an area of sand/clayey sand deposits which could potentially serve as a shallow aquifer.

A concentric region with green to light brown colouration exists between 74.0 m and 134.0 m along the traverse. The resistivity value increases inward toward the light brown colour from 200.0 Ωm to 600.0 Ωm, and occurs to a depth of 35 m below the surface. This region indicates the possible presence of bituminous sand. The presence of highly resistive material is also observed between at 144.0 m and 174.0 m. With a range from 220.0 to 890.0 Ωm, this region could be indicative of high bitumen concentrations to a depth of approximately 15 m.

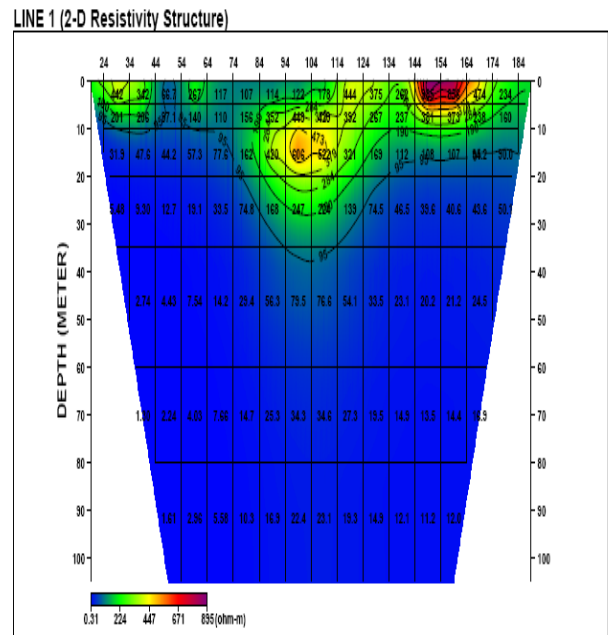
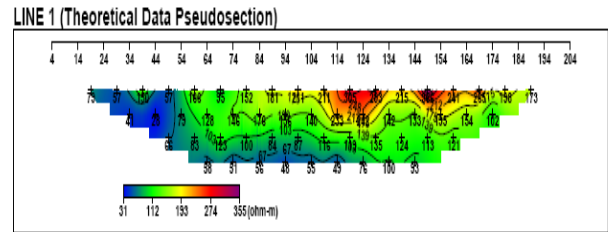
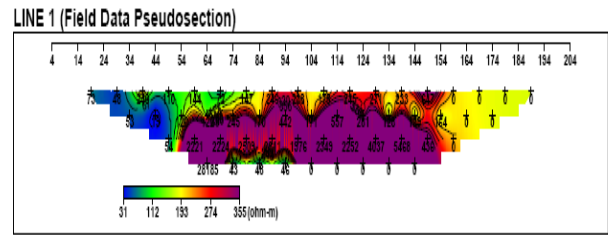


Figure 5. Inverted resistivity section along the traverse.

The blue coloured areas in the inverted resistivity section of Figure 5 between depths of 45.0 m and 100 m do not indicate regions with geological material of low resistivities, but rather ‘blind’ region where no reliable resistivity data could be recorded.

Magnetic Survey

In the magnetic geophysical technique, the absolute magnetic field of the earth is measured. Magnetic investigation can yield important data about geological structures. The magnetic survey was carried out along five traverses across the study area (Figure 2) using the proton precession magnetometer (model number c-810/826, serial number C328). Two magnetic readings, as well as a GPS reading, were taken at 5 m intervals on each traverse to facilitate easy plotting and correlation. The data obtained were then processed correcting for diurnal and geomagnetic variations. Finally, the

magnetic field readings were interpreted using the WinGlink [TM] version 1.62 software.

Profile by profile interpretation showed different anomaly signatures which are indicative of susceptibility contrasts in the underlying earth materials. The modelled subsurface structures from the magnetic profiles indicate a maximum depth to basement of about 300m below the subsurface. The ground magnetic contour of the study area is shown in Figure 6. Regions with close contour lines are indicative of abrupt changes in material while regions with sparse contour lines suggest a gradual change in the underlying material. The red to light brown areas in Figure 6 represent areas with high magnetic field intensity (ranging between 35,400 and 36,600 nT) in the north-eastern parts of the study area. The observed high magnetic field intensities in this area could be indicative of relatively thin (non-magnetic) sedimentary overburden overlying the deeper (magnetic) basement rocks. The yellow to green coloured areas (magnetic intensity values of between 32,800 and 35,000 nT) are interpreted as areas with moderate overburden thickness and tilted basement rocks. The western parts of the study area is characterised by low magnetic field intensities (31,200 to 32,200 nT) as indicated by the blue to purple regions in Figure 6. These areas could indicate thick overburden with greater depths to the basement rocks.

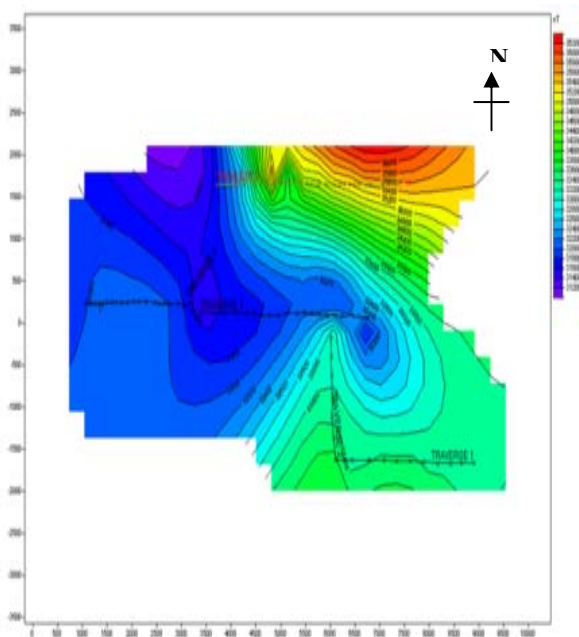


Figure 6. Ground magnetic contour map of the study area.

Since the observed magnetic data suggest that the depth to the basement rocks increases towards the south-western parts of the study area, flow is expected to take place in this direction. The oil seepage observed in this area seems to support this idea.

CONCLUSIONS

The high resistivity contrast between oil sands and its host geology, as well as its significant thickness relative to depth, are characteristics that have made geo-electric exploration useful in successfully mapping out regions of occurrence (McConnell and Glenn, 2008; Bauman, 2005). Nigerian oil sands seem to have the same geo-electrical effect as water with considerable content of dissolved deposits (Adegoke *et al.*, 1981), and show similar characteristics with the oil sands found in Athabasca, Canada (Dada, 2005) which have typical resistivity values ranging from approximately 110 Ω m to 1,800 Ω m (McConnell and Glenn, 2008).

Modelling the likely subsurface structures from the measured magnetic profiles with the constructed strata from the electrical methods suggests that oil sand deposits are present and substantial in the study area with a maximum depth to basement of about 300m. The oil sands deposit has concentrated presences trending to the SW direction of the study area. The deposit seems to commence at a depth of around 2 m extending to depths of approximately 40 m in this region.

Due to limitations encountered in this study (rugged topography and difficulty in assessing some areas) and the great economic importance of these deposits, it is recommended that further geophysical techniques be employed (such as electromagnetic and seismic methods) to evaluate the reserve estimate of the oil sand deposits. These deposits could serve as economically viable deposits for exploitation and provide a source of financial income to the community, state and nation at large, thus achieving one of the goals of the Vision 2020 programme of the Federal Government of Nigeria.

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